Advances in Reliability, Safety and Security, Part 9 – Kołowrocki, Dąbrowska (eds.)
© 2024 Polish Safety and Reliability Association, Gdynia, ISBN 978-83-68136-21-0 (printed), ISBN 978-83-68136-08-1 (electronic)

Advances in Reliability,
Safety and Security

ESREL 2024
Monograph Book Series

Real-Time Three-Dimensional Safety-Security Assessment Of Process Facilities In Critical Areas

Giulia Marroni[a], Dino Dentone[b], Stefano Crosara[b], Sanneke Kuipers[c],
Valeria Casson Moreno[a], Gabriele Landucci[a]

[a]Department of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino 2, 56126 Pisa, Italy
[b]DataCH Technologies, Via Leonardo da Vinci, 5, 57100 Livorno, Italy
[c]Institute of Security and Global Affairs, Leiden University, Turfmarkt n.99, 2511 DP Den Haag, the Netherlands

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Abstract

Industrial sites that store and process high amounts of hazardous chemicals can become attractive targets of intentional attacks. In fact, the consequences of an intentional attack might be catastrophic and could escalate generating the so-called domino effects, with serious effects on people and the environment. Another key characteristic connected to such events is their dynamic escalation, which cannot be well depicted by current safety-security assessment tools. In this work, we present a comprehensive tool to assess the risk of integrated safety-security and related domino effects, which is based on three-dimensional (3D) real-time approach. The graphical interface of the tool is the 3D reconstruction of the plant, which is generated through inspections using a drone. Real-time data are then associated to the sensible elements of the plants, e.g., pressure/temperature condition of a storage rank. The tool evaluates probabilities and 3D consequences of accidents, updating them based either on real-time data or user inputs. The consequences and risks associated with potential domino effects are also modelled in the tool. The use of the tool allows for the mapping of plant vulnerability, risk and supports the evaluation of weaknesses and need of additional countermeasures. A simplified version of the tool was used this work to demonstrate its potentialities on a case study.

Keywords: real-time assessment, dynamic risk assessment, safety and security integration, cascading effects

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1. Introduction

The need of safety improvement for Seveso installations asks for more advanced tools for risk estimation, evaluation, management, and communication. In fact, besides considering technical aspects, such as malfunctions, process upsets and organizational aspects, such as personnel attention and motivation to safety culture (Ale et al., 2014), external events may contribute to failures, such as Natech – Natural-technological scenarios (Rossi et al., 2022) as well as security-related events, i.e., intentional attacks (Marroni et al., 2024). All those aspects may not be easily investigated with conventional quantitative risk assessment (QRA) techniques and tools, which are known to be static, thus unable to estimate the variation of risks due to operation or changes during the lifecycle of a production plant (Kalantarnia et al., 2009). Moreover, these tools may not be adequate to cope with the challenge of managing safety and security concerns in a coordinated manner, as quantitative comprehensive approaches are still lacking.

Therefore, the development of Integrated Safety-Security (ISS) approaches is necessary to reduce the vulnerability of people and the environment to these emerging threats. Given the dynamic nature of domino effect accidents and the different kind of escalation of security events, ISS approaches may benefit from dynamic real-time approaches (Marroni et al., 2022). In fact, integrating the common methodology for risk evaluation adopting real-time plant data (from process operations and from the external environment) in an innovative software framework and supporting three-dimensional (3D) visualization of results, may result in a major step forward for ISS aspects management. Moreover, automatization of procedures, real time data acquisition and simulation are elements that are consistent with the current European trend of automation and digitalization of the industrial sector is the framework of Industry 4.0 (Wahlster, 2012). Dynamic and 3D approaches are also beneficial for the management of emergency in case of a loss of containment, since a quick-running, real-time tool can help emergency squads in quickly detecting high-risk zones to secure.

In the last decade, DataCH Technologies has collaborated with several Italian Port Authorities, with the aim to build an information system to support the rapid and efficient management of emergencies related to hazardous materials handling, storage and transport in port areas and to share the necessary information through an easy-to-use interface supported by 3D graphics. From the experience gained in the support to port facilities and in the framework of the LIFE20 ENV/IT/000436 – LIFE SECURDOMINO project (SECURDOMINO in the following), the software tool was extended for the assessment of fixed industrial facilities with the aim to manage and monitor in real time and on a single 3D platform i) complex ISS scenarios and associated risks; ii) the documentation, administration and logistics of an industrial facility.

The present works deals with the presentation of the SECURDOMINO software tool and related methodology for the real time hazard and risk assessment and major accidents triggered by external acts of interference. A sample application is presented to highlight the benefit and potentialities of the tool, discussing potential future developments.

2. Methodology

2.1. Overview

In this work, we present a methodology for a real-time 3D interactive mapping of hazards and risks associated with ISS in industrial facilities, which was implemented in a specific software tool. The methodology consists of the five following steps:

1. Preparatory phase
2. Plant inspection, performed by drone photogrammetry;
3. Three-dimensional reconstruction of the plant on a graphic interface;
4. Coupling of real-time and/or static data and documentation to each mapped element;
5. Real-time evaluation of consequences of an accidental/intentional release, to support emergency planning.

In Step 1, the documentation associated with the facility under analysis is collected and reviewed; this includes process flow diagrams, plant layout, equipment datasheet, safety and emergency procedures. In this way, the critical elements of the plant can be identified and analyzed, as detailed in Section 2.2

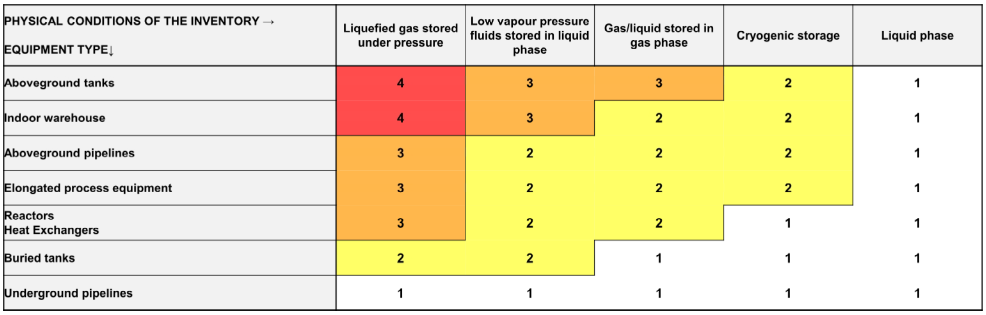
This preliminary step guides the Step 2 of the methodology, which entails the inspection of the facility using a drone in order to obtain the information to reproduce the plant on a three-dimensional (3D) interactive map; this part is examined in Section 2.3 of the paper. The 3D map is then built using the aerial photogrammetry technique, as detailed in Section 2.4. In Step 4 methodology, the map is made interactive by associating information to critical elements, as explained in Section 2.5. Namely, relevant data and information can be made available: this includes buildings, meteorological conditions, and equipment features (operating condition, substances stored, etc.). Moreover, management systems are available and can be monitored.

The final step of the methodology is the real-time evaluation of consequences, which is detailed in Section 2.6 of the paper. The tool is able to process either real-time data or user inputs in order to evaluate the vulnerability of the plant, i.e., the probability of release of hazardous substances, as well as the risk associated with the scenarios. Moreover, the tool is able to determine and evaluate potential cascading scenarios.

To show the potentialities of the tool, we present a simplified case study in Section 3 of the paper, while in Section 4 we discuss the results. Section 5 is instead dedicated to the future developments of the tool.

2.2. Preparatory phase (Step 1)

The preparatory phase is essential in order to understand and model the facility under analysis. This phase is carried out in collaboration with the staff of the plant, e.g., process engineer and plant manager and entails the review of plant documentation. The reviewed documentation includes but is not limited to: comprehensive safety reports, process description, control philosophy, plant layout, and equipment datasheet. In this way, the technical staff of the project is able to determine all critical elements associated with the plant. The screening method for selecting critical elements of the plant is hazard-based and was presented in a previous work (Marroni et al., 2023). In particular, the reference hazard chart in Figure 1 is adopted. Two factors are adopted to determine the criticality level: the physical conditions of the inventory, and the equipment type.



PHYSICAL CONDITIONS OF THE INVENTORY → EQUIPMENT TYPE↓	Liquefied gas stored under pressure	Low vapour pressure fluids stored in liquid phase	Gas/liquid stored in gas phase	Cryogenic storage	Liquid phase
Aboveground tanks	4	3	3	2	1
Indoor warehouse	4	3	2	2	1
Aboveground pipelines	3	2	2	2	1
Elongated process equipment	3	2	2	2	1
Reactors Heat Exchangers	3	2	2	1	1
Buried tanks	2	2	1	1	1
Underground pipelines	1	1	1	1	1

Fig. 1. Hazard-based equipment screening to support the mapping of critical asset, adapted from (Marroni et al., 2023).

The physical conditions of the hazardous inventory is clearly a crucial property to be assessed, as it deeply influences the way the release can evolve into different physical effects, e.g., fires, explosions, and dispersions. The equipment type is also an important feature. Namely, different equipment type may hold different amounts of hazardous substances. Moreover, the equipment type influences the visibility of the element, which is a crucial property when assessing intentional attack scenarios. Namely, more visible targets, such as aboveground tanks, might be more attractive for a threat compared to less visible equipment such as underground pipelines or buried storages.

By intersecting the physical conditions of the inventory with the equipment type in Figure 1, a score ranging from 1 (lowest) to 4 (highest) is assigned to each equipment in the facility, allowing to select the most critical ones, e.g., the ones with the highest score.

2.3. Plant inspection (Step 2)

Once the preparatory phase is complete, the technical team of the project is ready to begin with the inspection of the plant by drone flight. Before beginning, the staff of the project has to obtain the appropriate licensing and permitting in order to be able to proceed with the inspection of the plant. A small group composed of technical staff of the project is admitted on the plant to be analyzed. The group is accompanied by plant personnel, in order to follow safety procedures and not interfere with the normal operation of the plant.

The drone is then flown around the plant, and captures aerial videos, as well as pictures of the plant, which will then be used to build the graphical interface of the plant (see Section 2.4). Namely, these pictures contain all the necessary parameters for the 3D reconstruction, such as latitude, longitude, elevation, and inclination. Particular attention is reserved to the equipment classified as most critical through the hazard-based screening carried out in Step 1 (see Section 2.2). It should be noted that there might be critical elements that are not located outdoors, but rather indoors, such as material packages stored in warehouses. Such elements cannot be captured using the drone, as its movement would be drastically hindered in indoor areas. In these areas, a professional camera is instead used to capture all the necessary images and videos. The professional camera is also used to shoot in the outdoors in order to capture distinctive graphical, such as textures. Moreover, the benefit of combining aerial photogrammetry with photos taken with a professional camera is the ability to capture smaller elements, e.g., safety systems such as sprinklers or monitors.

Using tools such as drones and cameras allow for the necessary material to be captured in a span of a few days, according to the dimension and complexity of the plant to reconstruct. This makes it a very powerful and convenient methodology, as it is accurate, quick, and does not interfere with plant operations.

2.4. Three-dimensional reconstruction of the plant on a graphic interface (Step 3)

The 3D reconstruction of the plant is obtained by processing the pictures taken in Step 2 into the 3D rendering software Agisoft Metashape. Agisoft Metashape is a tool designed by Agisoft LLC for creating 3D spatial models and map using the photogrammetry technique (Agisoft, 2023). Photogrammetry, particularly aerial photogrammetry, involves the analysis of photographs taken at different heights and angles to create 3D models of physical objects and/or entire environments; this technique, also utilized across diverse fields such as by tech giants like Google (Google, 2019), forms the backbone of our modeling. The decision to employ photogrammetry over alternatives like LIDAR is driven by the specific demands of the project. While LIDAR excels in capturing intricate details within limited spaces, such as densely equipped rooms, our focus lies in accurately portraying process facilities while integrating real-time assessment of vulnerabilities and risk.

Consequently, opting for LIDAR would result in overly complex models with an unsustainable computational burden.

The 3D reconstruction of the plant is carried out on two different levels. Initially, a preliminary on-field 3D reconstruction serves as a practical test. The "on-field" reconstruction allows the technicians to verify the quality of the model in real time. Namely, the pictures taken by the drone and the cameras tend to be influenced by meteorological conditions, such as sunlight. Additionally, the analysis of the "on-field" 3D reconstruction guides further inspections of the site, as areas and elements that are not well represented can be easily identified. Once the quality is considered sufficient, the technicians will then begin with "high-quality" 3D reconstruction.

Once the reconstruction is complete, the model is cleaned up, optimized, and verified. Then, it is converted in proprietary formats and passed to an in-house developed 3D real-time engine that enables the multimedia management of the 3D scene.

Beyond the use of captured photos and videos, the technicians employ post-processing techniques to refine and enhance the visual aspects of crucial elements within the 3D model. Notably, specific sub-models are created from scratch by the graphics from DataCH. Figure 1 shows how the sub-model of an atmospheric vertical tank was created and implemented in the 3D landscape. Figure 1 (a) shows the how the atmospheric tank was recreated using only the data captured by the drone. Figure 1 (b) instead shows the enhanced atmospheric tank sub-model to be implemented in the interface of the tank. This procedure was already effectively employed for the reconstruction of port facilities; for more details the Reader is referred to (Ovidi et al., 2018).

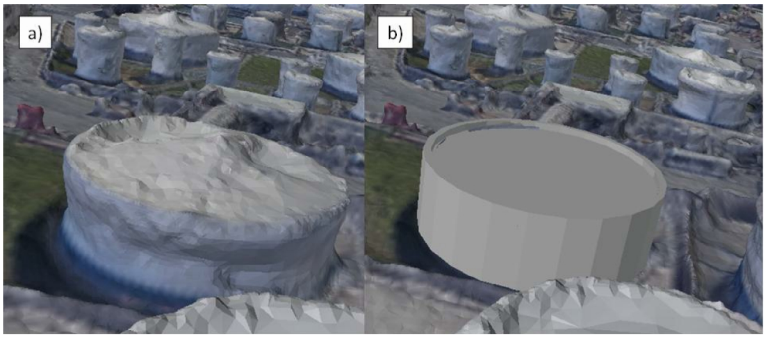
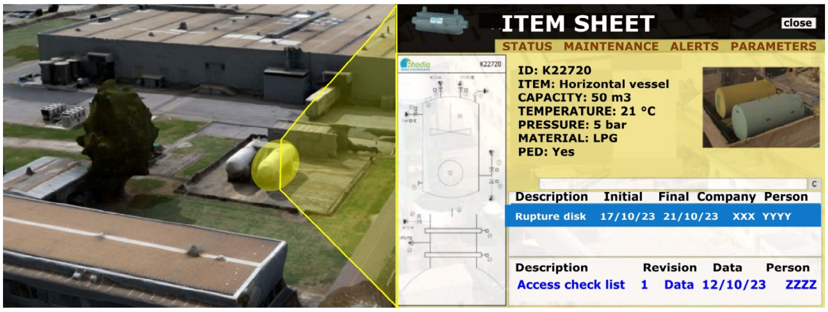


Fig. 2. Comparison between the model obtained from: (a) photogrammetry; (b) the manually enhanced 3D model.

2.5. Coupling of data and documentation to mapped elements (Step 4)

Once the 3D reconstruction is complete, the base for the interface of the tool is complete. The next step according to the methodology presented in Section 2.1 is to associate data and documentation to the elements of the plants. For these reasons, critical equipment and barriers are dynamic elements in the 3D reconstruction, meaning that the user can click and interact with them. Figure 3 shows an example of interaction with the interface of the tool. By clicking on the horizontal cylinder in the interface, a tab opens showing identifying elements of the equipment, such as the name, sketch, nominal properties, as well as a list of technical documentation available for consultation.



ID: K22720
ITEM: Horizontal vessel
CAPACITY: 50 m3
TEMPERATURE: 21 °C
PRESSURE: 5 bar
MATERIAL: LPG
PED: Yes

Description	Initial	Final	Company	Person
Rupture disk	17/10/23	21/10/23	XXX	YYYY

Description	Revision	Data	Person
Access check list	1	Data 12/10/23	ZZZZ

Fig. 3. Example of interactive equipment tab implemented in the tool.

The process equipment tab shown in Figure 3 has other sub-tabs, which can be utilized by the user to store important information and documentation, such as maintenance reports, P&ID (piping and instrumentation diagrams), etc.. If the tabs of all equipment are periodically updated, then the tool also serves as a management tool, where all information is comprehensively stored and is ready for browsing. For instance, this facilitates third party (e.g., Competent Authorities) inspections. Additionally, the tool is equipped to receive, store, and process real-time data. For the purposes of ISS risk assessment, two are the main categories of real-time data which are necessary for the analysis. The first category of real-time data is meteorological data. Weather data treatment is of fundamental importance to provide real-time consequence assessment results. In particular, the most relevant weather parameters are: wind speed, wind direction, relative humidity, ambient temperature and stability class. Such information can be obtained through a weather station, which can be inexpensively be installed in the plant if not already present. The second class of parameters are process parameters connected to the functions of the plant. The type of data depends on the type of process and equipment; for example, the parameters of interest for a liquid storage tank are level, pressure, and temperature. Such information can be derived by the control system installed in the plant, which can be connected to the tool.

2.6. Real-time evaluation of consequences following an accidental/intentional release (Step 5)

The final step of the methodology is the development of algorithms for ISS risk assessment and related domino effects. The tool operates in two different modes, a "default" mode and a "custom" mode. The "default" mode is thought for less experienced user, and hence does not allow the modification of significant parameters for ISS risk assessment. For example, in the "default" mode, the leak diameter for security scenarios, e.g., explosive, arson or firearms, were adapted from conventional release diameters proposed by (American Petroleum Institute, 2008). The same reference was used for the leak diameters of conventional safety events.

On the other hand, the "custom" version allows more advances users to set the preferred values of leak diameters. Release conditions can be either set by the user or, when possible, are directly retrieved from the control system of the analyzed equipment in order to obtain a real-time scenario.

As for meteorological conditions, the tool is equipped for processing real-time information as outlined in Section 2.5. If no real-time information is available, then average weather data from the site are used, and default stability condition 2F and 5D are used, in accordance with conventional safety analyses (Center for Chemical Process Safety, 2010)

The preliminary version of the tool includes the evaluation of physical effects of fires. In modelling physical effects, we considered that the tool should be able to support emergency operations after a major accidents. For this reason, it was essential to use and develop physical effects models that constitute a good compromise between computational run times and accuracy. For pool and jet fires, we utilized integral models based a multi-point source approach (Hankinson and Lowesmith, 2012); instead, the conventional point-source model was used to model the heat radiation coming from a fireball (van den Bosch and Weterings, 2005). A repository of all models for physical effects can be consulted on the official website of the project (Securdomino, 2023). More details can be found by the Reader in (Ovidi et al., 2018).

The frequency f_{FO} of the final outcomes included in the preliminary version of the tool is obtained by applying (1):

$$f_{FO} = f_A \cdot P_S \cdot P_I, \tag{1}$$

where f_A is the frequency of the intentional attack or unintentional loss of containment, P_S is the probability of success of the attack and P_I is the probability of ignition.

The frequency f_A of intentional attacks was retrieved from (American Petroleum Institute, 2013) based on the analysis of the context where the plant operates and the past history of the plant. Instead, f_A for accidental scenarios was retrieved from (American Petroleum Institute, 2008) based on the type of equipment.

P_S and P_I were evaluated by applying the Event Tree Analysis. In particular, the methodology developed by (Casson Moreno et al., 2022) was adopted. In their work, specific decisional gates were developed to model the performance of security barriers, such as fences, closed-circuit television (CCTV), emergency response team; then, security barriers were integrated with conventional safety barriers such as sprinkler systems. This integration aimed to capture the synergistic performance of both physical security and safety barriers. The resulting product of this integration was the development of ISS Event Trees.

The final results shown by the tool on the 3D interface are both risk and vulnerability contours, according to the choice of the user. The compatibility matrix of the Italian land-use planning legislation (Laurent et al., 2021), which was used for risk assessment, and it is shown in Table 1. Territorial categories are assigned for each combination of frequency and impact zone ranging from A (densely populated residential areas) to F (industrial establishments and non-built respect area). The Reader is referred to (Laurent et al., 2021) for more details on the definition of the Italian territorial categories. It should be noted that using a compatibility matrix for risk assessment entails that the overall risk assessment is scenario-based. For this reason, the user can browse through the different scenarios coming from the Event Tree Analysis.

On the other hand, the overall vulnerability of the plant is obtained by cumulating the probability of success of all scenarios considered in the Event Tree Analysis, and hence it does not take into account potential consequences. Still, vulnerability constitutes a pivotal parameter for the analysis of intentional attack scenarios (Landucci et al., 2020), and was for this reason implemented in the analysis.

Hence, the two parameters serve different purposes. Visualizing the risk allows for the user to determine the most critical scenarios, while visualizing the vulnerability allows the user to determine which areas of the plant are the least protected from an intentional attack.

Table 1. Compatibility matrix used for risk assessment, adapted from (Laurent et al., 2021).
The capital letters indicate the vulnerability class of the territory (from F – industrial area, to A – highly populated residential area).

Impact zones →	High lethality	Starting lethality	Irreversible injuries	Reversible injuries
Pool/jet fire →	12.5 kW/m^2	7 kW/m^2	5 kW/m^2	3 kW/m^2
Fireball →	Fireball radius	350 kJ/m^2	200 kJ/m^2	125 kJ/m^2
Frequency f_{FO} ↓				
$f_{FO} < 10^{-6}$	DEF	CDEF	BCDEF	ABCDEF
$10^{-6} < f_{FO} \leq 10^{-4}$	EF	DEF	CDEF	BCDEF
$10^{-4} < f_{FO} \leq 10^{-3}$	F	EF	DEF	CDEF
$f_{FO} > 10^{-3}$	F	F	EF	DEF

3. Application to a case study

A preliminary version of the tool was used to analyze a case study. The layout of the plant is shown in Figure 4. The plant was active in the last 30 years and is situated in a country with a mild socio-economic and political climate. The plant is located in an industrial context and confines with a railway on the North side. The plant stores Liquefied Petroleum Gase (LPG) in two 50 m^3 aboveground tanks and ethanol in three 10 m^3 buried tanks.

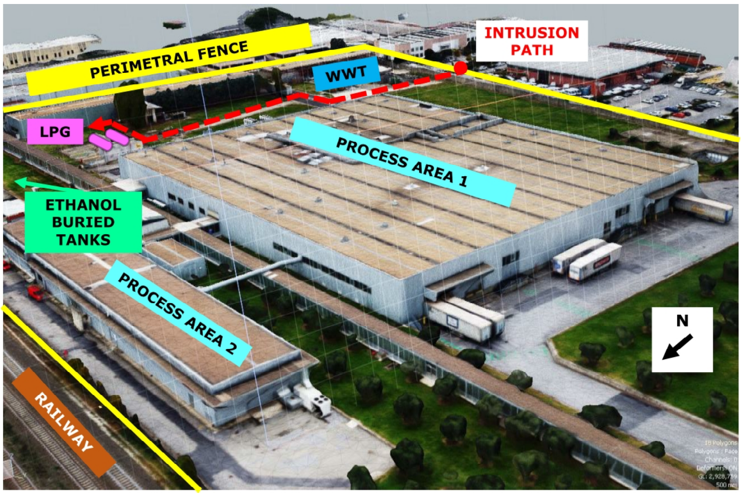


Fig. 4. Layout of the case study. WWT = waste water treatment.

In order to determine the critical equipment, the hazard-based method presented in Section 2.1 was adopted. LPG storage tanks are aboveground tanks storing a pressurized liquefied, hence they were assigned a score of 4 according to Figure 1. Ethanol can be instead considered as a fluid with low vapor pressure stored in a liquid phase, which is stored in buried tanks; so it was assigned a score of 2 according to Figure 1. Hence, the LPG storage tanks are the critical elements for this plant, and they are therefore the focus of the analysis.

Figure 4 also shows the exemplifying intrusion path walked by a potential attacker to target the LPG tanks. The attacker enters the facility during night shift by the trespassing the Southern perimetral fence. The attacker runs along the waste water treatment (WWT) area, reaches one LPG tank and sabotages a connection flange. This leads to a 1’’(25.4 mm) leak of LPG.

As the ISS risk assessment algorithms are complex and require a lot of information, we will analyze a simplified case study for the sake of exemplification and brevity. In particular, we will analyze the most sever scenario, which is the unmitigated attack scenario, i.e., the scenario in which the attacker is able to completely carry out the attack. Another conservative yet simplifying assumption is the neglection of the intervention of safety barrier; for this reason, we considered a release duration of 3 minutes. The security staff of the facility is highly trained; hence, a time of 4 minutes is assumed to be necessary to neutralize the attacker. More details about the performance of safety-security barriers are reported elsewhere (Casson Moreno et al., 2022).

To assess the physical effects connected to the release of LPG, we adopted nominal storage condition and we considered the wind blowing at 2 m/s.

4. Results and discussion

Considering the heat and sparks that might be generated in order to sabotage the connection flange, it is possible to assume a unitary probability of ignition, $P_I = 1.0$. Hence, the scenario analyzed is this case is a jet fire originating from the release of LPG from the flange.

The first step in the methodology outlined in Section 2.5 is the assessment of the frequency of the final outcome. Hence, we should firstly determine the frequency of an intentional attack. According to the context in which the plant operates, a value of one intentional attack in the life of the plant has been chosen leading to $f_A = 0.03$ events/y; this value is the second lowest value according to the references in Section 2.5.

To determine the probability of attack success P_S the ISS Event Tree was built and a simplified version of it is represented in Figure 5.

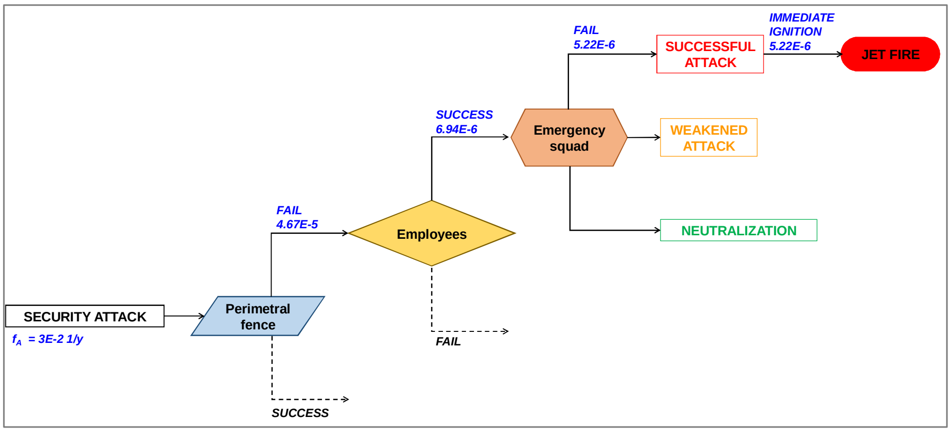


Fig. 5. Event tree for the attack scenario which path is shown in Figure 4.

Namely, the ISS Event Trees can be quite extended, as the attack could be successful through different combination of events, such as the failure of different barriers. In the unmitigated scenario considered in this work, we considered the following sequence of events: the attacker trespasses the fence, but is identified by employees of the night shift. The employees alert the emergency squads, which fail to act, leading to an unmitigated scenario escalation. Using the barrier performance data in (Casson Moreno et al., 2022), the attack success probability is $P_S = 1.74 \cdot 10^{-4}$.

So, by using (1), a final outcomes frequency $f_{FO} = 5.22 \cdot 10^{-6}$ events/y is obtained. It should be noticed that the order of magnitude of this frequency is comparable with the frequency of final outcomes deriving from unintentional accidents (Uijt de Haag and Ale, 1999).

The intensity of the physical effect, e.g., the heat radiation of the generated jet fire is evaluated through the use of the models discussed in Section 2.5. Figure 6(a) shows the contour of heat radiation (% of the maximum heat radiation in the flame center, 238 kW/m^2).

It should be noticed that the second LPG tank is completely engulfed in the jet fire flame. This could damage the tank and lead to its catastrophic rupture, generating critical domino effects with amplified consequences. The assessment of such event chains is part of the future development of the tool, which are discusses in detail in Section 5.

Risk-based contours and territorial vulnerability classification are shown in Figure 6 (b). In conventional analyses, such contours would be two-dimensional, while the tool allows a 3D assessment where the contours are represented by half-spheres. This allows the users to take into consideration potential displacements of heights and could for example assess the effects in tall buildings or when there are significant height displacements. The effect of building is of particular interest for dispersions, as they can significantly influence the concentration of toxic and flammable substances; moreover, the presence of buildings, and more in general congestion, particularly affects the potential for an explosion (Uijt de Haag and Ale, 1999). Still, the 3D representation of buildings in case of fire can still support further considerations, even if the integral models used in consequence assessment do not actively account for the presence of buildings.

By observing the risk contours, we can see that there are other sensible elements that are involved in the major accident. In fact, in the scenario depicted in Figure 6 (b) the risk contours reach Process Area 1 (see Figure 4), with potential damages to people and assets. The analysis of this simple scenario still allows to highlight the criticality of intentional attack scenarios and the need to deal with them using dedicated approaches.

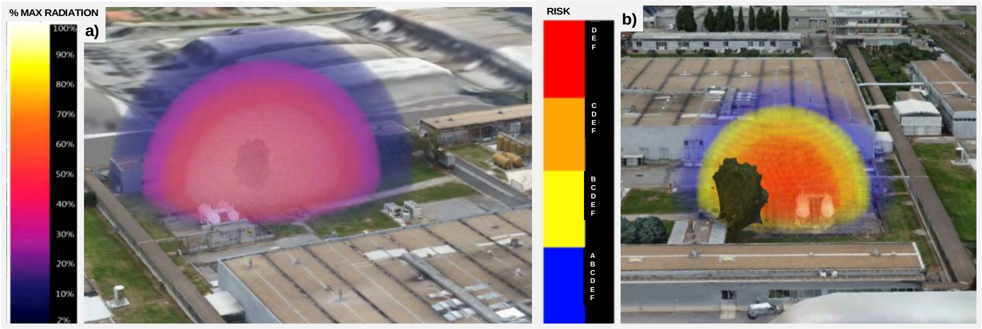


Fig. 6. Jet fire heat radiation contours (a) and territorial vulnerability classification (b).
The contour of heat radiation (a) are given as % of the maximum heat radiation in the flame center (i.e. 238 kW/m^2).
The territorial vulnerability classes are defined in Table 1.

5. Future developments

The ISS risk assessment algorithms included in the tool are still under development. Hence, the tool will be greatly improved in the next years. Firstly, the algorithms related to the assessment of physical effects will be completed; in this way, the tool will be able to compute the physical effects associated with explosions and dispersions. Another improvement is related to the assessment of domino effect chains, which could take place in larger and more complex process facilities, such as tank farms, refineries, chemical clusters, where tens of tanks or other hazardous units are placed near to each other.

Finally, other metric for assessing risk will be added to the tool; in particular, the routine for the evaluation of the local specific individual risk (Uijt de Haag and Ale, 1999) will be developed, along with acceptability criteria specifically tailored to ISS scenarios.

Another opportunity for improvement is related to the first steps of the methodology, related to the 3D reconstruction. the methodology will be tested on different types of plants in order to test its potentialities and improve it. Namely, the industrial landscape can vary significantly from plant to plant, and the development of additional specific procedures for 3D reconstruction might be necessary.

6. Conclusions

The integration of safety and security scenarios is a critical issue for the protection of process facilities. In this work, we presented methodology for the 3D real-time assessment of ISS scenarios. The methodology is implemented in a specific tool, which allows the evaluation of ISS scenarios. The tool is able to receive, store, and process real-time data. Moreover, it allows users to store documentation related to the critical equipment, allowing for an easier management of the may documents produces in a process facility.

A simplified version of the tool was used to highlight the potentialities of the present methodology. The 3D visualization of the scenarios has multiple advantages. The first one is that emergency squads have a quick tool to visualize impact zones and therefore better assess evacuation and mitigation measures. The second advantage is that the management has a tool that quicky allows to visualize the risk of either conventional or customized scenarios. This can be of support in decisional processes, for example while deciding which safety or security barriers to improve in the site. Moreover, the tool could be used for the training of employees. Emergency scenarios can be simulated in the 3D tool in order to show emergency procedures and critical barriers or equipment to employees.

The drawback of having a risk-assessment with low running times is related to the accuracy of physical models. The integral models used in the tool are less accurate compared to others available; however, considering the scope of the tool (especially for the management of emergency), the lower accuracy is considered acceptable to enhance the run-time speed of the tool.

The developed methodology could be thus implemented in conventional QRA studies in order to guide practitioners and plant managers in identifying critical attack scenarios and critical barriers, as well as guiding potential improvements and allocation of resources.

Acknowledgements

This study was in part developed within the project LIFE20 ENV/IT/000436 – LIFE SECURDOMINO “Seveso sites: assessment of integrated safety-security hazards and risks and related domino effects” with the contribution of LIFE program of the European Union. The Authors would also like to thank the facility of Bolton Personal Care (Stabilimento Personal Care di Bolton) for their support.

References

Agisoft. 2023. Agisoft Metashape Professional Edition: Features. Accessed 29th December 2023. https://www.agisoft.com/features/professional-edition/.

Ale, B., van Gulijk, C., Hanea, A., Hanea, D., Hudson, P., Lin, P-H., Sillem, S. 2014. Towards BBN based risk modelling of process plants. Safety Science 69, 48-56.

American Petroleum Institute. 2008. ANSI/API Standard 581 – Risk-Based Inspection Technology. American Petroleum Institute, Washington D.C., U.S..

American Petroleum Institute. 2013. ANSI/API Standard 780 – Security Risk Assessment Methodology for the Petroleum and Petrochemical Industries. American Petroleum Institute, Washington D.C., U.S..

Casson Moreno, V., Marroni, G., Landucci, G. 2022. Probabilistic assessment aimed at the evaluation of escalating scenarios in process facilities combining safety and security barriers. Reliability Engineering and System Safety 228, 108762.

Center for Chemical Process Safety. 2010. Guidelines for Chemical Process Quantitative Risk Analysis. John Wiley & Sons, Hoboken, NJ, U.S.A.

de Dianous, V., Fiévez, C. 2006. ARAMIS project: A more explicit demonstration of risk control through the use of the bow-tie diagrams and the evaluation of safety barrier performance. Journal of Hazardous Materials 130, 220-233.

Google. 2019. Google Maps 101: how imagery powers oyur map. Accessed 25th February 2024. https://blog.google/products/maps/google-maps-101-how-imagery-powers-our-map/

Hankinson, G., Lowesmith, B.J. 2012. A consideration of methods of determining the radiative characteristics of jet fires. Combustion and Flame 159, 1165-1177.

Kalantarnia, M., Khan, F., Hawboldt, K. 2009. Dynamic risk assessment using failure assessment and Bayesian theory. Journal of Loss Prevention in the Process Industries 22, 600-606.

Laurent, A., Pey, A., Gurtel, P., Fabiano, B. 2021. A critical perspective on the implementation of the EU Council Seveso Directive in France, Germany, Italy and Spain, Process Safety and Environmental Protection 148, 47-74.

Landucci, G., Khakzad, N., Reniers, G. 2020. Physical Security in the Process Industry. Elsevier, Amsterdam, the Netherlands.

Marroni, G., Piemonte, A., Tamburini, F., Caroti, G., Pannocchia, G., Landucci, G. 2022, An Interdisciplinary Approach Towards the Integrated Safety-Security Assessment of Process Facilities Operating in the Maghreb Context. Chemical Engineering Transactions 91, 517-522

Marroni, G., Casini, L., Kuipers, S., Dentone, D., Mossa Verrem M., Overdijk, W., Casson Moreno, V., Landucci, G. 2023. Real-Time Assessment of Integrated Safey-Security Scenarios Triggering Cascading Events in the Process Industries. Chemical Engineering Transactions 99, 349-354.

Marroni, G., Casini, L., Bartolucci, A., Kuipers, S., Casson Moreno, V., Landucci, G. 2024. Development of fragility models for process equipment affected by physical security attacks. Reliability Engineering & System Safety 243, 109880

Ovidi, F., Picconi, L., Landucci, G., Chiavistelli, T. 2018. A three-dimensional visualization tool to support HSE management of chemical facilities. Institution of Chemical Engineers Symposium Series 163.

Rossi, L., Casson Moreno, V., Landucci, G. 2022. Vulnerability assessment of process pipelines affected by flood events. Reliability Engineering & System Safety 219, 108261

Securdomino. 2023. Open web repository of models and barriers data. Accessed 29th December 2023. https://securdomino.eu/open-web-repository/

Uijt de Haag, P.A.M., Ale, B.J.M. 1999, Guidelines for Quantitative Risk Assessment (Purple Book). Committee for the Prevention of Disasters, the Hague, the Netherlands.

van den Bosch, C.J.H., Weterings, R.A.P.M. 2005. Methods for the calculation of physical effects (Yellow Book). Committee for the Prevention of Disasters, The Hague, The Netherlands.

Wahlster, W. 2012. From Industry 1.0 to Industry 4.0: Towards the 4th Industria Revolution. Forum Business meets Research.